International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 6, Issue 6, Dec 2016, 13-20
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EFFECT OF AGEING TEMPERATURE ON FATIGUE BEHAVIOR OF CARBON BLACK REINFORCED ALUMINIUM COMPOSITES

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ABSTRACT

The objective of the research work was to investigate the effect of ageing temperature and amount of carbon black (CB) on fatigue behaviour of Al/CB composites. The Al/CB composites were synthesis by using liquid metallurgical technique and characterised for fatigue properties using rotating beam fatigue machine at room temperature. The result shows that CB and ageing temperature increasing the fatigue life of the Al/CB composites due to its formation of precipitation during ageing process. The ageing temperature of 170℃ gives higher fatigue life compare to ascast condition but over ageing temperature 270℃ gives lower fatigue life. The addition of CB shows fatigue strength is improved significantly. The fatigue fracture surfaces were studied using electron microscope for detection of failure mechanism.

KEYWORDS: Carbon Black (CB), Al/CB Composites, Higher Fatigue Life & Lower Fatigue Life

Received: Oct 26, 2016**; Accepted:** Nov 09, 2016**; Published:** Nov 15, 2016**; Paper Id.:** IJMPERDDEC20162

Original Article

INTRODUCTION

Particle reinforced Al alloy based metal matrix composites (MMCs) are promising candidates due to their exceptional offering high specific stiffness, fatigue strength, wear resistance and tailorable thermal expansion. The ceramics reinforcement in the in the Al can improve the fatigue strength, which depends on the geometry of particle, loading percentage and orientation of reinforcement. Several investigations showed that reinforcement of particles influence on microstructure of composites and fatigue behaviour of MMCs. [1–6]. The fatigue behaviour depends on the intrinsic properties of alloy and reinforcements and also secondary processing such ageing along with test parameters. Addition of reinforcement the MMCs displayed superior stress level fatigue properties with higher percentage of reinforcement leading to longer fatigue life. Few studies showed that addition of reinforcement enhanced resistance to the fatigue crack propagation. Recently carbon nano tube reinforced aluminium MMC shows superior elastic modulus, fracture toughness and even thermal properties hence it gains lot of interest [7]. But the cost of carbon nano tubes perform is so high that Al MMCs have not used widely. To solve the problems of the high cost of the carbon nano tubes and potential hazards in their handling, the carbon nano powder was used many applications.

Extensive review of the literature available on Al MMCs reveals that aging has a significant influence on

hardness and other mechanical properties of these composites [9-11]. The literature available on fatigue behavior of Al/ carbon black (CB) composite and influence of heat treatment on fatigue behavior of Al MMCs are limited. Since Al/CB composite could be used for automobile and aerospace applications because of its tailor made properties, there is scope for investigation of fatigue properties and influence of heat treatment on fatigue properties of composite. The objectives of the present research work was to investigate of fatigue properties of the as cast CB reinforced Al MMCs through stress life (SN) and reliability stress life (RSN) curves and establishment of SN and RSN curves for aging and over aging heat treated composite with varied temperature and time.

EXPERIMENTAL STUDIES

Al 6061 alloy has having good mechanical properties with formability hence Al6061 alloy was selected as matrix material for current research work and its chemical composition are given in the Table 1. Carbon black of particle size 3 to 5 nm was selected as a reinforcement materials.

Development of high efficient MWCNT doped KNN based energy storage devices

Table 1: Typical Composition of Aluminium Alloy 6061

Elements	Al	Mg	Si	Fe	Cu	Zn
%	Balance	0.8-1.2	0.4 – 0.8	0.7	0.15-0.40	0.25

Al/CB composites were fabricated by using stir casting method with varying % of CB. Al ingots were cleaned by acetone to remove dust particles and acidic impurity. The nitrogen gas used to create inert atmosphere during the melting process. Known amount of preheated CB mixed with 1% of Mg powder and introduced into the molten metal during stirring process. Mixed molten metal slurry was poured into the preheated metal die. After cooling the specimens were removed and machine as per requirements.

Al/CB composites were subjected to solutionizing heat treatment by placing the standard specimens in muffle furnace at a temperature 500^0C for a period of 90 minutes, followed by quenching in water. Artificial ageing heat treatment was carried out by placing the solution heat treated specimens in muffle furnace for duration of about 2 h at a temperature of 170^0 C, followed by air cooling. Over ageing heat treatment was carried out by placing the solution heat treated specimens in muffle furnace for duration of about 2hrs at a temperature of 270^0 C, followed by air cooling.

Experiments have been conducted on rotating beam fatigue testing machine. The test specimens are to be machined from test samples with the aid of especially sharp cutting tools, to avoid any other additional deformation or over heating during machining. Then they are ground on precision machine and finally polished in longitudinal direction of the specimen with the finest grade of emery. During machining care must be taken that no undercut occurs at the transition of fillets and cylindrical section. The test specimen must be greased with non-corroding grease to protect against undesirable corrosion. In the above-mentioned method, machine the test specimens according to drawing. The standard size fatigue specimen used for conducting experiment is as shown in Figure 1. For rotating bending fatigue loading (cantilever beam) tests were conducted using rotating fatigue machine as shown in Figure 2. The specimen was fixed into the machine collets firmly and loaded poise weight as per required stress (bending stress). The fatigue machine rotates at constant speed of 600 rpm and the number of rotation is recorded using cycle counter. The load cell was pasted between the specimen holders to measure the radial load. Below bearing support a part catcher is fixed to collet specimen after fracture. Specimens tested at various loads provide data for plotting a Stress vs. Number of cycles (S/N) curve.

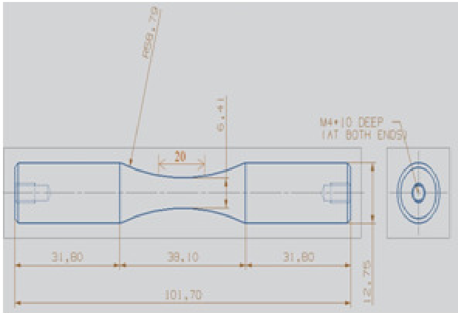

Figure 1: Specimen Dimensions for Rotating Beam Fatigue Test

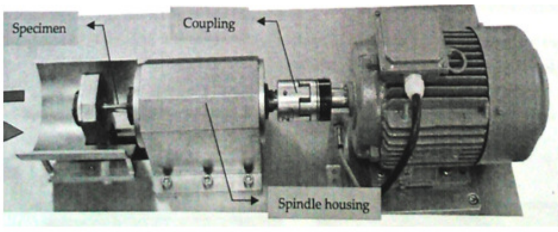

Figure 2: Rotating Beam Fatigue Machine used for testing the Specimen

RESULTS AND DISCUSSIONS

Rotation beam fatigue (cantilever) stress amplitude versus number of fatigue cycle until failure at lab temperature is shown in Figure 2. During the course of investigation of effect of ageing on fatigue behavior of as cast Al, 5% CB/Al and 10% CB/Al composites results were plotted in Figure 2(a), 2(b) and 2(c) respectively.

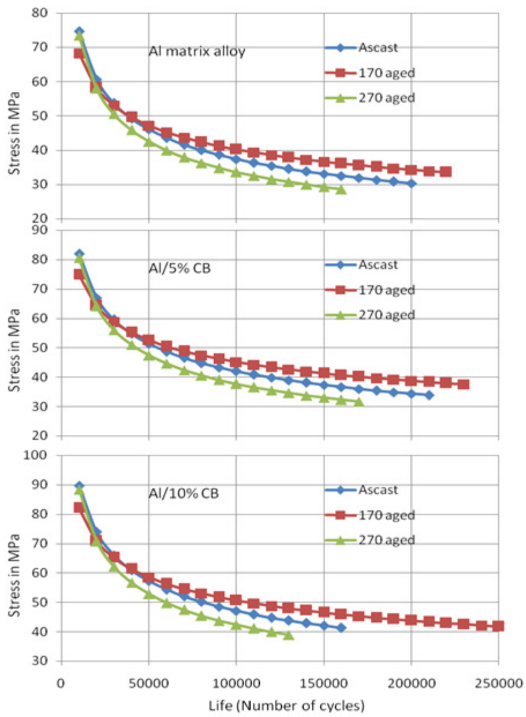

Figure 3: S–N Curves for Fatigue of a) Ascast Al, b) 5% CB and 10% CB Reinforced Composite for Ascast, 170 °C and 279 °C Ageing Condition

The fatigue life of Al/CB MMCs is longer than that of ascast matrix alloy irrespective of ageing conditions. In

other hand the fatigue life of the Al/CB high stresses converges against the ascast Al alloy. Figure 2 (a) shows fatigue life of the Al matrix for three different conditions such as ascast, 170 °C aged and 270 °C aged conditions. 170 °C ageing condition shows the longer fatigue life following by ascast condition but 270 °C shows highly poor performance due to over ageing conditions. The fatigue life limit at 16e4 cycles in ascast conditions, nearly 22e4 cycles for 170 °C aging conditions but just 14e4 cycles for over aging condition (270 °C). The similar trend is observed in Al/5% CB and Al/10% CB MMCs shown in Figure 2(b) and 2(c). Generally al and its alloy do not follow a constant fatigue strength but they show continually decreasing fatigue resistance. According to fatigue limit of the Al matrix is 75 N/mm^2 which is as per published results [12-13].

When the Al and Al/CB MMCs are artificially aged at 170 °C, the fatigue limit is increased to 90 N/mm^2. At lower cycles, the fatigue resistance of the aged Al and Al/CB composites are highly improved. By addition of just 5% of CB to Al matrix alloy under ageing condition, the fatigue limit reaches more than 90 N/mm^2. The fatigue average stress limit at 55 N/mm^2 in 10% CB reinforced Al MMCs and the matrix alloy is 45 N/mm^2 as shown in Figure 3.

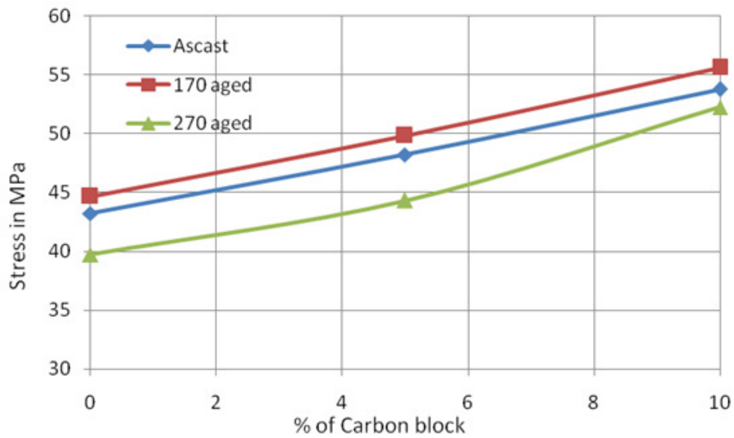

Figure 4: Effect of CB on Average Fatigue Stress of the Al MMMCs for Different Ageing Conditions

Formation of precipitates associated with strengthen is influenced by the dislocation of substructure in the alloy matrix. Previous work [14-16] on Al alloys has provided some evidence for clusters of vacancy concentration obtained by raising the solution temperature and increasing the quenching rate and during storage at room temperature. The precipitates formed during aging at 170°C are needle shaped and are considered to be an intermediate phase. The higher vacancy concentration obtained by raising the solution temperature and increasing the quenching rate promotes the clustering process, and results in a finer scale of precipitation. It is now well established that the development of significant levels of hardness in Al-6061 is associated with the formation of β-Mg2Si. However the level depends on the size and spacing of the β precipitates.

The latter is controlled by nature of β nuclei (which are normally GP zones) and their temperature of formation. The absence of GP zone formation in the composite therefore has a significant effect on the size and morphology of the β precipitates and resultant age hardening. The material contained β-Mg2Si in a coarse Widmanstatten morphology, homogeneously nucleated precipitates in peak aged condition was found by many researchers in unreinforced alloys.

FRACTURE SURFACE

Significant changes in microstructure of precipitation of second phase particles in MMCs subjected to aging and over aging affecting the fatigue property were observed through fractography analysis as shown in Figure 4. The fracture surface of Al alloy has cast defects such as voids as shown in Figure 4(a), which leads to fewer fractured blocks on the surface of Al alloy at ascast conditions. At ageing conditions the voids are not seen few cracks are seen on the surface Al as shown in 4(b). The size of cracks and voids are decreased in size of the primary cracks. The rotational fatigue beam fracture surfaces of the MMCs exhibit that cast defects along with CB cluster are fracture origins at room temperature as shown in Figure 4(c)-4(F). But it is very difficult to determine the origin of the fracture since there is no radiative lines on the surface of the composites. In some places the cavitations in the MMCs (origin of multiple fractures) are existing in MMCs as shown in Figure 4(c). Due to ageing the cavitations decreases with ageing. This damage dominated by a diffusion-controlled process. In other hand different crack initiation for aging condition were reported Al MMC [17]. The cracks are initiated due to stress concentration sources such as CB inclusions during casting. In other hand CB reacts with Mg (which present in the alloy) during ageing is evident strengthening effect of CB as seen in this research results.

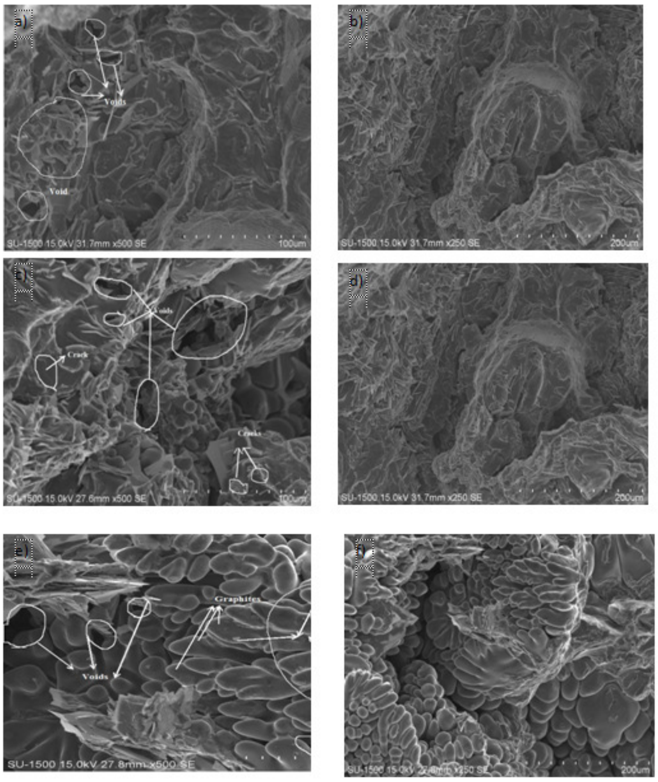

Figure 4: Fracture Surface of a) Al, b) Al Aged c) 5%CB, d) 5%CB Aged e) 10%CB, and f) 10% CB Aged Reinforced Composite Showing Fatigue Fracture Origin at Cluster of Whiskers

CONCLUSIONS

- It is found that there is a wide scatter in fatigue life of Al and Al/CB MMCs at each stress life and fatigue life.
- Aging Al and Al /CB composite specimens clearly show that there is a significant improvement in fatigue life.
- There is a drastic decrease in fatigue life of both Al and Al/CB MMCs which were over aged compared to as cast MMCs.

- The ageing precipitation behavior of the composite alloy is greatly different from the unreinforced Al alloy.
- The addition of CB and artificial aging greatly improves the fatigue limit of the composite.
- Significant changes in fracture surface second phase particles in hybrid composites subjected to aging and over aging het treatment affecting fatigue property were validated through fractography analysis.

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